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Automatic Level Control of Coupled Tank Non Interacting System

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ABSTRACT

This paper deals to control the liquid level in a coupled tank non interacting systems by using different control techniques. Usually the liquid undergoes chemical or mixing treatment in the tanks but it is necessary to continuously control the level in the tank and the flow between tanks which is an integral part of chemical engineering systems. In this paper different control schemes like internal model control (IMC), cascade PID, conventional PID controllers are used to control the tanks level in set point. The performance of each control techniques are studied and compared. Conclusions are made from MATLAB simulations. This study would prove to be beneficial to several industrial and household applications like boiler level control, household water supply and many more.

Key words: Coupled non-interacting tank, PID, Cascade PID, IMC

1. INTRODUCTION

The liquid level digital control system is a simple system which can tackle a complex problem faced by most process industries - liquid level control in coupled tank. [5]It automatically maintains the desired water level in a tank/container through a digital process wherein the pump is switched ON when water level is below a pre - determined minimum level and it is switches OFF when the level crosses a certain maximum. It thus prevents the tank from overflowing and maintains the water at a fixed level thereby maintains saving both electricity and water.

Accurate liquid level measurement and control is an essential part of most process industries including:

- Food Processing, Diary and Beverages Industry.
- Chemical Production, Processing and Storage Plants
- Petroleum and Petrochemical Industry
- Water and Waste Water Treatment Plants
- Pollution Control Plants
- Textiles, Pulp and Paper Industries
- Energy and Power Generation Plants
- Shipping and Marine Industry

Proper control of water level in tanks is necessary in order to avoid wastage of water. In household system the water is initially stored in underground tank (UGT) and then pumped up to overhead tank (OHT). People tend to switch on the pump when the taps go dry and tend to switch it OFF when the OHT overflows. This leads to unnecessary wastage of water this leading to water scarcity during times of need. Hence it is important to properly control the water level in tanks.

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In the given system there are 3 tanks - 2 process tanks and one reservoir tank with a capacity of approximately 2 litres each. A 230 V submersible pump located in the reservoir tank and it pumps water from the tank to the first process tank. Once water in the first tank reaches a minimum level, it flows to a second process tank through a 24V operated solenoid valve. The supply to the submersible tank is turned off as soon as the water in the first process tank reaches high level. Similarly supply to the solenoid valve is cut off when the water in the second process tank reaches set point. [5]The whole process is controlled using 2 microcontrollers- 8051 and atmega8l along with power supply and relay circuits. [1]Different control mechanisms are compared in this paper to find which best suits the system. [2]The main controller used is a PID controller which is used to make a discretized model of the system. The controlled system output is studied and compared with that of uncontrolled system to get better understanding also, [3], [4] IMC (internal model control) controller is used is analyse the system behaviour.

Earlier this control used to be manual but involved errors. So these controllers had to be automated. With the advent of digital electronics and invention of microprocessors and microcontrollers automation became simple and this technology could be used to control water level at the desired set point.

2. SYSTEM MODELLING

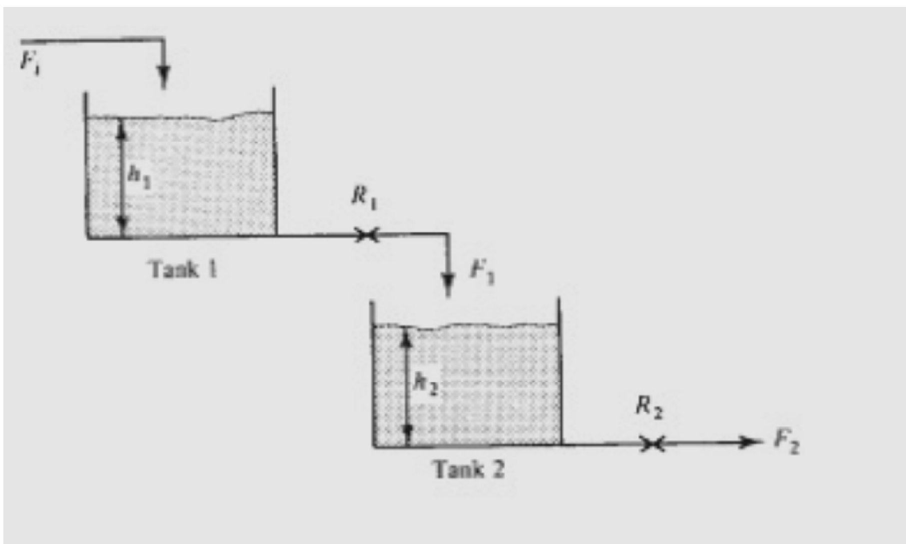

Figure 1: Two Tank Non Interacting System

The system is modelled as a first-order system. The tank acts as a fluid capacitor where fluid enters the tank (behaving as charged particles entering a capacitor) and leaves the tank. According to mass balance relation between the incoming fluid and outgoing fluid,

$$Q_{in} = Q + Q_{out}$$

Where, Q_{in} is the flow rate of water coming into the tank, Q the net rate of water storage in the tank, and Q_{out} is the flow rate of water going out from the tank. If A is the cross-sectional area of the tank, and h is the height of water inside the tank at any instant. The liquid is to be of constant density, the tanks to have uniform cross- sectional area, and the flow resistances to be linear. Our problem is to find a transfer function $H_2(s)/Q(s)$. The approach will be to obtain a transfer function for each tank,$Q_1(s)/Q(s)$ and $H_2(s)/Q_1(s)$, by writing a transient mass balance around each tank; these transfer functions will then be combined to eliminate the intermediate $Q_1(s)$ and produce the desired transfer function. A balance on tank 1 tank 2 gives

$$q - q_1 = A_1 \frac{dh_1}{dt}$$

$$q_1 - q_2 = A_2 \frac{dh_2}{dt}$$

The flow-head relationships for the two linear resistances are given by the expressions

$$q_1 = \frac{h_1}{R_1}$$

$$q_2 = \frac{h_2}{R_2}$$

Combining the above equations and introducing deviation variables give the transfer function for tank 1

$$\frac{Q_1(s)}{Q_2(s)} = \frac{1}{\tau_1 s + 1}$$

Where, $Q_1 = q_1 - q_{1s}$, $Q = q - q_s$ and $\tau_1 = R_1 A_{11}$

Combining the above equations and introducing deviation variables give the transfer function for tank 2

$$\frac{H_2(s)}{Q_1(s)} = \frac{R_2}{\tau_2 s + 1}$$

Where,

$H_2 = h_2 - h_{2s}$ and $\tau_2 = R_2 A_2$

Having the transfer function for each tank, we can obtain the overall transfer function H2(s)/Q(s)

$$\frac{H_2(s)}{Q(s)} = \frac{1}{\tau_s + 1} \frac{R_2}{\tau_{2s} + 1}$$

Notice that the overall transfer function above is the product of two first-order transfer functions, each of which is the transfer function of a single tank operating independently of the other tank.

2.1. Hardware Specification

Diameter of tank =0.135m.

Height of tank = 0.145m.

Area of the tank (A_1, A_2) = 0.0591m2.

Capacity of the tank = 1.9 litres

Rate of change of flow= (volume to be controlled)/ (time taken to fill) = 0.017 for l sec

Resistance (R_1, R_2, R_3) = (height of liquid in tank)/ (rate of

Change of flow) = 7.647

Constant (1, 2) = A_1 x R_1 = A_2 x R_2 = 0.44

$$G(s) = \frac{K}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

After substituting the values in above equation

$$G(s)\frac{1}{(0.1936s^2+0.88s+1)}$$

Time constant (τ) = 0:705sec

Time constant (τ_1) = 0:5sec

Delay time (τ_d) = 0:265sec

3. CONTROLLER DESIGN

There are many methods available for tuning of controllers to achieve a good and stable response. It's mainly being used in industries.

3.1. PID Controller

A proportional-integral-derivative controller (PID controller) takes a measured value from the process and compares it with the set point. The difference is the error signal which tries to bring the output to the set point value.

The standard equation for PID controller is

$$u(t)=Ke(t)+\frac{1}{T}\int_0^t e(\tau)d\tau+T_d\frac{de(t)}{dt})$$

Where, e(t) is the error signal, K is the constant, u(t) is input signal and Ti and Td are the integral and derivative time constant.

Taking Laplace transform of the equation, we get

$$G(s)=K\left(1+\frac{1}{sT_i}+sT_d\right)$$

The parallel form of PID controller is given as:

$$u(t)=K_p e(t)+K_i\int_0^t e(\tau)d\tau+K_d\frac{de(t)}{dt}$$

With its Laplace transform

$$G(s)=K_p+\frac{K_i}{s}+sK_d$$

We can easily convert the parameters from one form to another by noting that

$$K_p=K$$

$$K_i=\frac{K}{T_i}$$

$$K_d=KT_d$$

Where Kp: proportional gain;

Ki: integral gain;

Kd : derivative gain;

Ti: integral time constant and

Td: derivative time constant.

Table 1
Controller parameters

Type of Controller	*PID*	*IMC*	*Cascade (Master)*
Proprotional Gain (K_p)	3.19	1.23	0.2259
Integral Gain (K_I)	1.88	1.136	0.6653
Derivative Gain (K_D)	0.1325	0.22	0.0329
Settling Time (t_s)	7.6 SEC	5.8 SEC	2.15 SEC

The process is simulated in the MATLAB, initially the open loop response is taken by giving step input to the process. Through the response the ultimate gain of the process can be determined and by using zeigler nicholas method PID controller can designed. Kp, Ki, and Kd values tuned such that the response obtained is the most appropriate one.

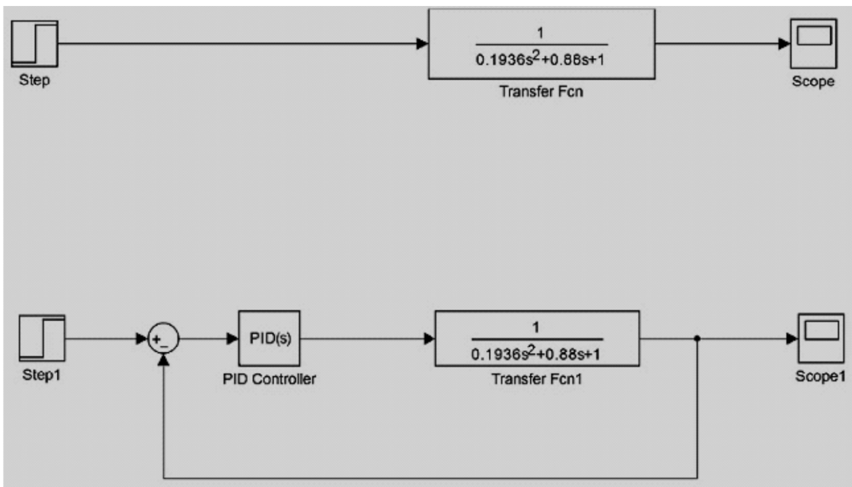

Figure 2: Open loop and closed loop simulation using PID

3.2. Cascade Controller

Cascade controller is basically used for higher order systems in order to reduce the effects caused by the loops. In this system the process is divided in two loops primary loop and secondary loop. Both the loops have different controller and the output of one loop acts as a set point for the other.

The inner loop is the secondary loop while the outer loop is the primary loop. The transfer functions are generated and their respective PID controllers are designed. The variable which is to be controlled first is taken in the inner loop as an input to PID controller. While the other variables are taken outside.

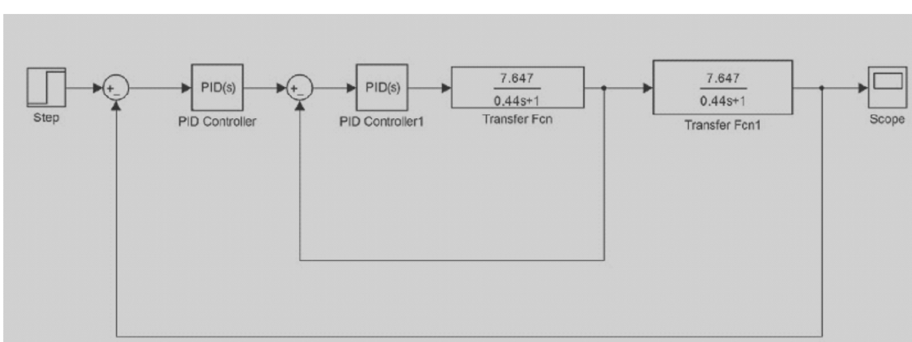

Figure 3: Cascaded controller design

3.3. Internal Model Controller

IMC (internal model control) is most widely used for linear processes such as single input and single output processes. This controller is easy to design and has good disturbance rejection capability also it has better robustness properties. In primary context IMC has been widely applicable to linear Processes.

Open loop control is basically the control without feedback where the desired output is difficult to reach for this reason it is not as commonly used as closed- loop control systems.

Where, Gc(s) is the controller transfer function and Gp(s) is the process transfer function.

$$Y(s) = R(s)\, G_c(s)\, G_p(s)$$

If we assume there exists a model of the plant with a transfer function modelled as Gpm(s) such that Gpm(s) is an exact representation of the process (plant), i.e. Gpm(s)= Gp(s), then set point tracking can be achieved by designing a controller such that:

$$G_c(s) = G_{pm}(s)^{-1}$$

Hence the process model represents the process exactly but in real life applications this may differ from parent plant. In the fig() it is shown how an internal model and the parent plant takes input from the controller and gives output.

To simulate the process with IMC controller, both the transfer function of the process as well as the internal model are taken and connected according to the scheme. The transport delay is used to create delay in the process such that the control can be matched.

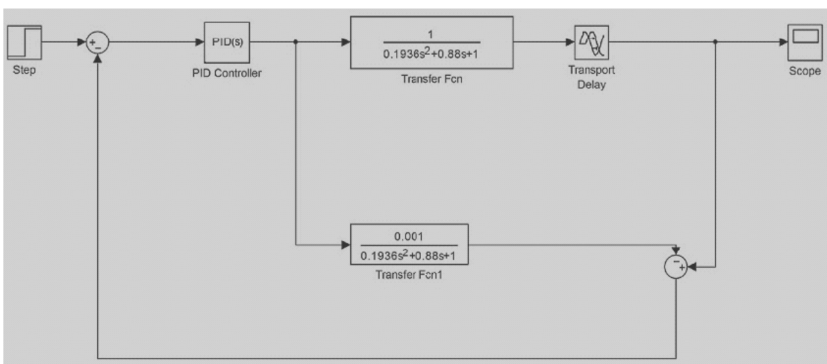

Figure 4: Simulation diagram of IMC controller

4. RESULTS

The system's response is analysed with three controllers along with its open loop response.

In the open loop response the process takes time to get settled, this is the reason why we go for feedback control due to accuracy problems.

In PID controller both rise time and settling time reduces as compared to open loop response. Though its peak overshoot is not good as compared to the other controllers.

Cascaded controller output response is far better than both the open loop response and PID controller response. It settles within 2sec and even the overshoot is not as high as PID.

IMC controller reduces the peak overshoot but it takes more time to get settled. This is mainly due to the difference between the parent model and the internal model.

Out of all the controllers implemented cascaded PID is giving the best response due to its low rise time and settling time. Apart from cascaded PID, single PID also proves to be effective.

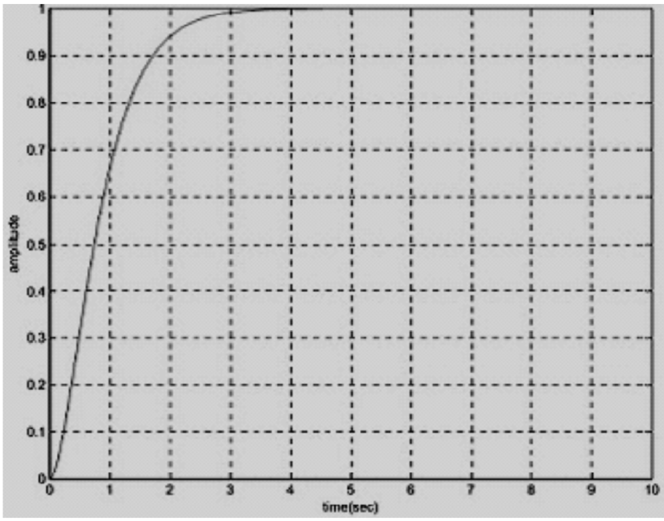

Figure 5: Open loop response

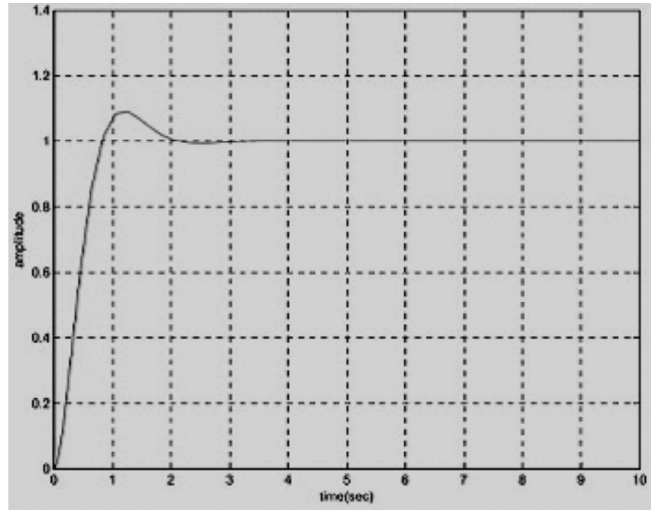

Figure 6: PID Controller response

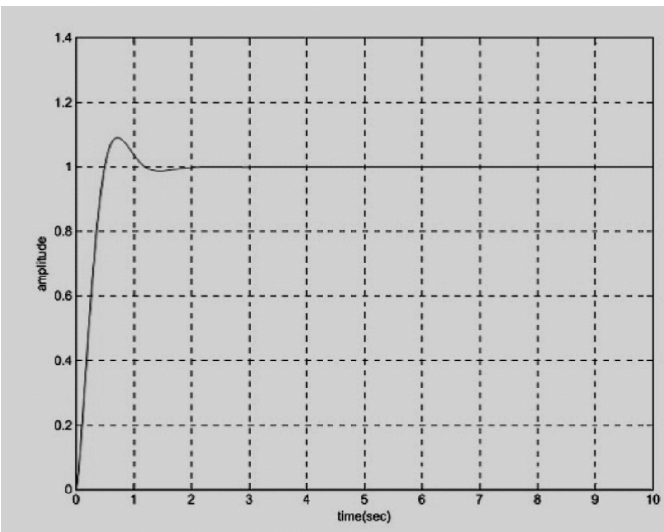

Figure 7: Cascade PID response

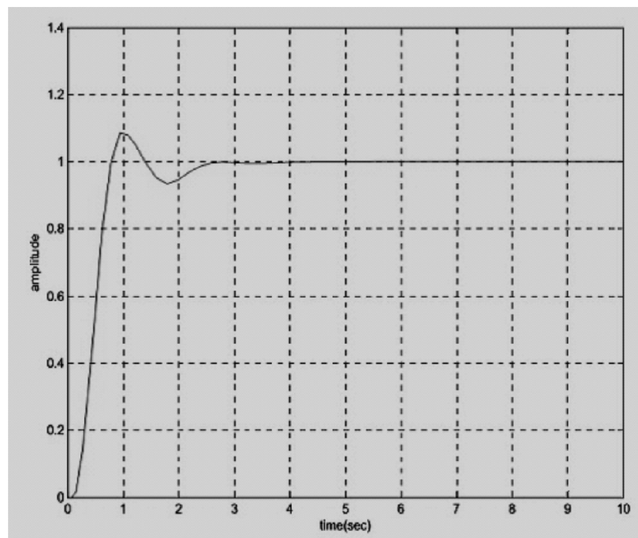

Figure 8: IMC controller response

Table 2
Comparison of Controllers performance

Parameters	*Open Loop*	*PID Controller*	*Cascade Controller*	*IMC Controller*
Rise Time	2.5	0.9	0.5	0.8
Settling Time	3.5	3.2	2	4
Peak	1	1.08	0.7	1.08

5. CONCLUSION

Eventually, the simulations and hardware set up in microcontroller are successfully implemented and the results are shown in the respective section of the paper.Three control methods are incorporated as part of this paper viz- Integral Model control (IMC), Cascade control scheme and PID controller.

From the simulation results it can be inferred that the advanced control schemes like IMC and cascade controller bring out the best results in comparison with PID controller, open loop and closed loop in terms of certain time domain parameters. Simulation results are shown alongside the corresponding controllers to fully comprehend the nature of the controller's behaviour to the input.

This paper overcomes the manual control of level and offers several advantages over the conventional level control and ensures reliable output in the long run.

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